# New Results from the SoftLAB Benchmark of Antenna Software


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***Abstract*— This paper gives an overview of the antenna software benchmarking activity that took place within the Software Group of the EurAAP association in 2009. A particular focus is brought to one of the proposed test case that consists of a non conventional horn antenna.**


## I. Introduction

Following the success of the previous editions [1]-[3], a new benchmarking run of the SoftLAB (Software on Line Antenna Benchmark) service has been launched in March 2009, during the EuCAP conference, in Berlin. It aimed at continuing the efforts that were originally initiated within the ACE NoE (Antenna Center of Excellence) from 2004 to 2007 to provide a European platform for the assessment of antenna softwares.

The benchmark is now organized within the Software Group of the EurAAP Association and is open to anyone developing or using antenna simulation tools. It is based on a yearly process (Fig. 1). Each year, a new run is organized in connection with the EuCAP conference. Indeed, this event (gathering a vast majority of the antenna community) is used as a milestone to:

- present and discuss the results of the last completed run,
- select the test cases for the next run.

This permits both a democratic process and fruitful scientific exchanges. It should be highlighted that anyone can join the discussion and propose its own structure as a potential candidate for benchmarking. The only constraint is to provide measurement results (only for the final stage as the benchmarking itself is supposed to be a blind process). Proposals from industrial partners are particularly welcome as they usually correspond to challenging and real life radiating structures.

Once the test cases have been agreed, the process continues online using SoftLAB [1], the specific Web-service that has been developed within the VCE (Virtual Center of Excellence is now the portal of the EurAAP association).

After registration in VCE, anyone can download all the needed information about the chosen test cases (geometry description, required simulation outputs, etc.) and analyse them with any simulation tool (either in-house or commercial). It is then possible to participate in the benchmarking by submitting the obtained simulation results. The run is open for a few months (typically from summer to December), and no results are visible before it is closed. At the end of the process (a couple of months before the next EuCAP issue), results are available in the portal. The philosophy of SoftLAB is to provide all useful data so that anyone can assess the capabilities of software regarding its own computation needs. No conclusion is drawn in SoftLAB as the objective is neither to express any viewpoint nor to support any tool.

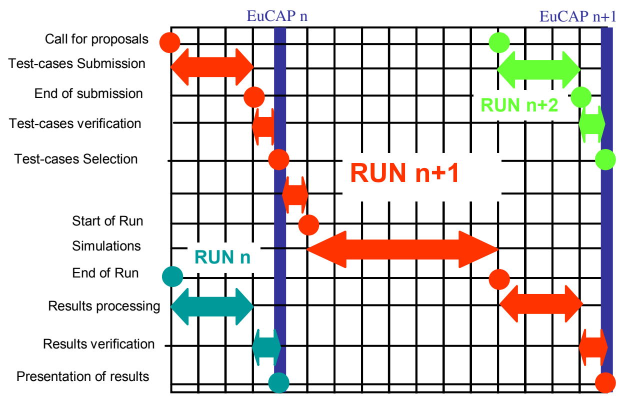


Fig. 1 Organization of a benchmark run

At the moment, four different benchmarking runs have been organized (from 2004 to 2009), which resulted in about 100 simulations performed by more than 20 contributors using various techniques and tools. All the results are available, which provides a unique information about available software tools and associated capabilities to address complex antenna problems.

The last benchmarking run (run #4, in 2009) consisted of 4 antenna test cases, selected during the meeting of the EurAAP Software Group that took place in March 2009 within the EuCAP conference, in Berlin.

This paper gives a general overview of this benchmark run and presents a few results.

## II. Presentation of Run #4

In 2009, four different antenna configurations have been considered for benchmarking:

- A high impedance surface, proposed by Telecom Paris (France),
- A circular array of resonant dipoles, proposed by NTUA (Greece),
- A switchable UWB patch antenna, proposed by KUL (Belgium),
- A non conventional horn antenna with an optimized profile, proposed by IETR (France).

These test cases are represented in Fig. 2. The complete description of these test cases can be found in SoftLAB and will not be given here.

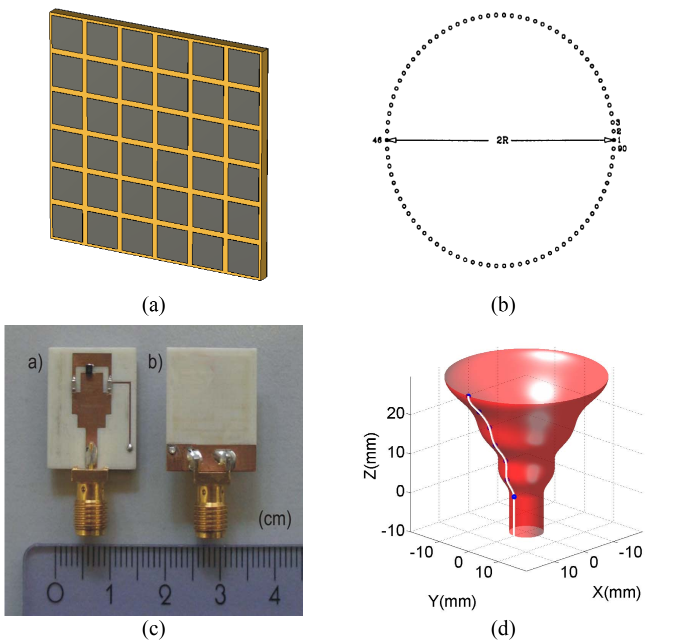


Fig. 2 Studied test-cases for the fourth benchmark run. (a) High impedance surface. (b) Circular array of 90 dipoles. (c) Reconfigurable UWB antenna. (d) Horn antenna with shaped profile optimized by genetic algorithm.

Despite the reduced number of configurations, this set of antenna structures permits to address various aspects:

- Both single elements and arrays,
- Different technologies (planar, wire and 3D),
- Reconfigurable elements (with switches integrated within the radiating element itself),
- Different excitations (lumped ports, modal excitation, plane wave excitation),
- Different frequency bands (UWB, 30 GHz, S band),
- Various output data (radiating patterns, input impedance, resonant frequencies, dispersion diagrams, etc.).

These test cases have been open for simulation from August to December 2009. A total of 10 contributions has been collected (the results can be downloaded from SoftLAB). The next section discusses one of the test cases more in detail and gives an overview of the obtained results.

## III. Example: Horn Antenna with Optimised Profile

### *A. Description of the test case*

This test case proposed to the antenna community an axis-symmetrical structure with a non conventional profile. The main motivation was to assess the capabilities of 3D solvers in analysing shaped 3D antennas. Furthermore, as the antenna under study is axis-symmetrical, this enables to benchmark true 3D general-purpose solvers and specific solvers dedicated to bodies of revolution (i.e. based on azimuthal modal expansions).

In this frame, a smooth-walled conical horn antenna with an optimised metallic profile has been proposed by IETR. The design tool is based on an in-house BoR-FDTD (body-of-revolution) solver combined with real-valued and binary-coded genetic algorithms [4]. As a result, the corresponding antenna designs often exhibit non intuitive shapes, thus providing relevant test-cases in the benchmark process of SoftLAB.

The design flow chart is represented in Fig. 3.

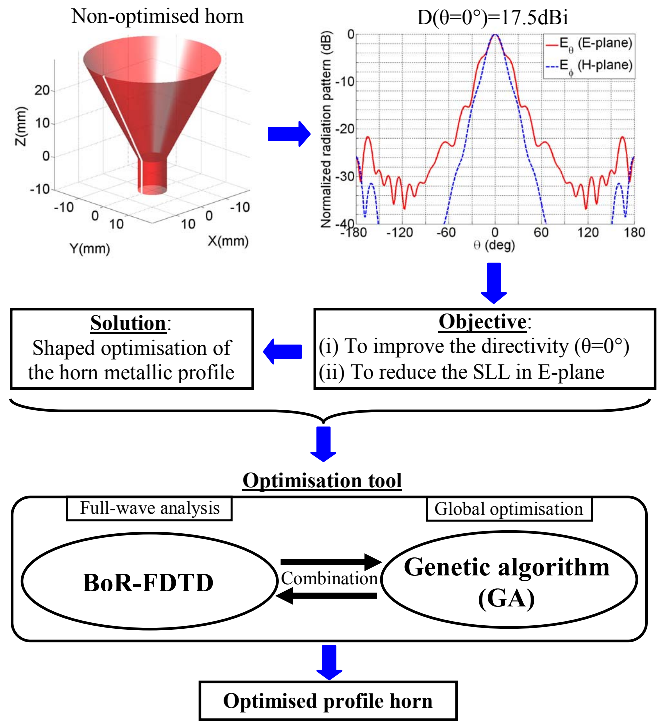


Fig. 3 Flow chart of the design approach leading to the proposed test-case structure.

As indicated in Fig. 3, the optimisation goal consists in improving the directivity of a non-optimised conical horn (with straight wall) while keeping the side lobe level (SLL) lower than -15dB and the back-radiation level lower than -20dB. The conical and optimised horns must have the same volume. The frequency band of interest is [27-32] GHz, and the centre frequency is 30.5 GHz. Both horns are fed by a circular waveguide ($Ø_{WG}$=8.34mm) operating in $TE_{11}$ mode.

The optimised horn is represented in Fig. 4. Its half profile is defined using 7 control nodes ($P_i$). A cubic spline interpolation between the control nodes has been used to reconstruct the real profile of the antenna. In addition, vertical half-tangents ($D_1$ and $D_7$) have been considered at nodes $P_1$ and $P_7$ respectively (as observed in Fig. 4). The locations of the nodes after optimisation are provided in Table I. These data are the only ones provided for benchmarking.

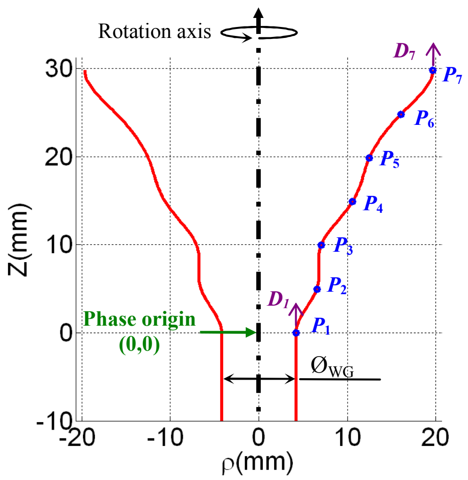


Fig. 4 Cross-section view of the smooth-walled optimised horn antenna.

TABLE I
LOCATION OF THE CONTROL NODES AFTER OPTIMISATION

| (mm) | $P_1$ | $P_2$ | $P_3$ | $P_4$ | $P_5$ | $P_6$ | $P_7$ |
|---|---|---|---|---|---|---|---|
| ρ | 4.17 | 6.55 | 7.03 | 10.60 | 12.50 | 16.07 | 19.67 |
| Z | 0.00 | 4.96 | 9.93 | 14.89 | 19.85 | 24.82 | 29.78 |

### B. Simulation Results

Four contributions have been collected (CST MICROWAVE STUDIO®, TICRA, UPC and IETR). The main features of the corresponding electromagnetic solvers are the following:

- CST MICROWAVE STUDIO® (CST MWS) is a specialist tool for the fast and accurate 3D electromagnetic simulation of high-frequency problems. CST MWS is the first commercial high-frequency EM simulation code to offer the advantages of both Cartesian and tetrahedral meshing in one 3D EM simulator. This extension joins innovations such as perfect boundary approximation (PBA)® and the thin sheet technique (TST)™ that combine memory efficiency and performance expected from time-domain simulators with the excellent accuracy of conformal methods [5]-[7]. For the simulation the transient solver of CST MWS 2010 is used together with a Cartesian meshing of 20 lines per wavelength. The horn profile is modelled as a PEC geometry with zero thickness,
- CHAMP 2.0.4 from TICRA, the software for the design, analysis and optimization of circularly symmetric corrugated or smooth horns. Mode matching was used for the horn interior and method of moments for the horn exterior [8]. The horn exterior was assumed 0.1 mm-thick and conformal to the horn interior. A number of 49 nodes was used to define the horn exterior, while the interior was described by a spline profile, available in CHAMP, passing through the 7 nodes given by IETR. The vertical half-tangent conditions were realized by inserting in the horn interior two additional nodes, $P_8$ and $P_9$, having the same ρ coordinates of $P_1$ and $P_7$, respectively, and a small displacement along *z*.
- FIESTA-3D [9] developed by UPC. FIESTA-3D is based on the method of moments (Galerkin) with RWG basis functions and several fast solvers (MLFMA, MDA-SVD, ACA, MSCBD). Here we have used the EFIE formulation with free-space Green's function and numerical source and test integration (4 quadrature points in both source and testing triangles). The fast solver is Matrix Decomposition Algorithm – Singular Value Decomposition (MDA-SVD). The feed is an infinitesimal *x*-directed dipole inside the circular wave guide, located at (0,0,-8) mm. No symmetry has been used. The overall number of unknowns is 15788. The MDA-SVD iterative solution average error compared to direct solution is 0.29 dB in E-plane and 0.16 dB in H-plane. This error is due to the approximation in the impedance matrix compression and the GMRES iteration stopping at 1% relative error.
- BoR-FDTD developed by IETR (Section III.A). The FDTD mesh is uniform (cylindrical coordinate system) and the metallic profile is assumed to be a PEC of zero thickness. It is modelled using a stair-case approximation. The mesh size is $\Delta\rho=\lambda_0/50$, $\Delta z=\lambda_0/50$. Uniaxial perfectly matched layers are used to truncate the computational volume.

The radiation patterns (in amplitude) have been computed at 30.5 GHz with the four solvers. They are represented in Figs. 5 and 6. The overall agreement between the four results is very satisfactory especially in H-plane (Fig. 6) for forward radiation and in E-plane (Fig. 5) for the main lobe and first side lobes. Nevertheless a few differences can be observed: FIESTA-3D provides slightly different results for |θ|>60° in E-plane and |θ|>100° in H-plane. In addition, the BoR-FDTD solver slightly over-estimates the backward radiation whereas CHAMP and CST MWS provide very close results. Additional results have shown that the phase patterns (not given here) are very close for all solvers. The near-field plots are not compared here since they are not available with the CHAMP tool. The reflection coefficient $S_{11}$ is represented in Fig. 7 ($S_{11}$ is not available with FIESTA-3D). The three results provided by CST MWS 2010, CHAMP and BoR-FDTD are very similar.

Although the studied horn has not been manufactured, we can conclude that the numerical results provided by the four tools are quite close. Some of the observed discrepancies could originate from the modelling assumptions mentioned above (non-zero thickness and horn exterior profile for CHAMP, stair-case approximation for BoR-FDTD, etc.).

Finally the main numerical features (mesh size, memory, computation time, etc.) are summarized in Table II. In particular we can notice that the directivity computed by the four solvers only differs by 0.1dBi.

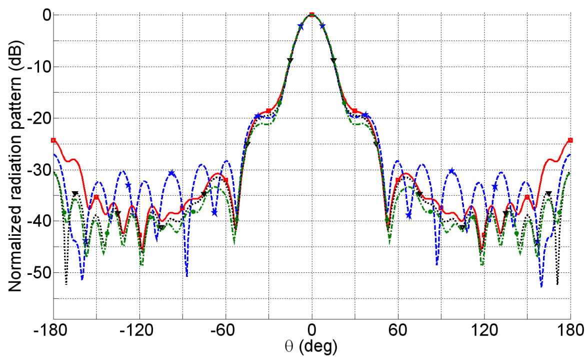


Fig. 5 Radiation pattern computed in E-plane at 30.5GHz. ─■─: BoR-FDTD. ─★─: FIESTA-3D. ··▼·: CHAMP. ─o─ : CST MICROWAVE STUDIO®.

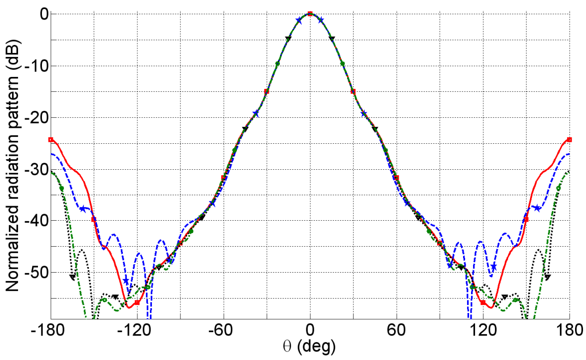


Fig. 6 Radiation pattern computed in H-plane at 30.5GHz. ─■─: BoR-FDTD. ─★─: FIESTA-3D. ··▼·: CHAMP. ─o─ : CST MICROWAVE STUDIO®.

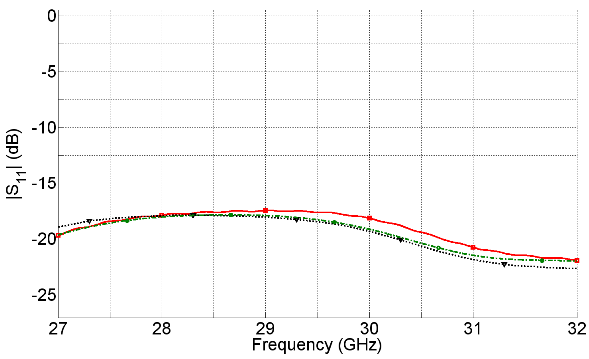


Fig. 7 Reflection coefficient $S_{11}$ computed over the frequency band of interest [27-32]GHz. ─■─ : BoR-FDTD. ··▼· : CHAMP. ─o─ : CST MICROWAVE STUDIO®.

## IV. Conclusion

This paper aimed at giving an overview of the antenna software benchmark that was organized within the ACE network of excellence. The paper was mainly focused on the last benchmark run that took place in 2009. The studied test-cases have been presented and simulation details have been given for one of them. More information can be found in the ACE website [1] where all results are available for all. The objective is now to continue this assessment activity within the EurAAP association. Interested people are kindly invited to join this effort by proposing challenging structures or/and by participating in the simulation process.

TABLE II
Main Benchmarking Indicators

| | **IETR** | **CST MWS 2010** | **UPC** | **TICRA** |
|---|---|---|---|---|
| **Methods / Solver** | BoR-FDTD [4] | Commercial [5-7] | FIESTA-3D MDA-SVD [9] | CHAMP (BoR Mode matching and MoM) [8] |
| **Mesh refinement** | λ/50 | λ/20 | avg=0.078λ max=0.26λ | λ/15 for MoM |
| **Computation time [hardware]** | 63 sec. + 5 sec. per frequency point for far-fields [Pentium 4 f=3.20GHz, 1 core used) 2 GB RAM] | 125 sec. [Dell Precision T7500] | 73 sec. for one frequency point [Intel Xeon X5482, 3.20 GHz, 8 cores] | 1.76 sec. per frequency point (almost linear scaling when increasing the number of points) - [dual processor laptop with 4 GB RAM] |
| **Memory size** | 20 MB | 88.7 MB | 407 MB | 40 MB |
| **Directivity at broadside** | 18.58 dBi | 18.64 dBi | 18.61 dBi | 18.68 dBi |

## Acknowledgment

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